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Integer lapped biorthogonal transform

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INTEGER LAPPED BIORTHOGONAL TRANSFORM

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ABSTRACT

In this paper, a type of lapped biorthogonal transform that can map integers to integers is considered. Based on the computational structure of the proposed lapped transform, an efficient multiplierless algorithm for the lapped biorthogonal transform (LBT), called integer lapped biorthogonal transform (IntLBT), is proposed. The proposed IntLBT is implemented by a series of dyadic lifting steps, and provides fast, efficient computation of the transform coefficients as well as the ability to map integers to integers. Application of the novel IntLBT in lossy image coding gains very competitive results comparing to the performance of the much more complex Cohen-Daubechies-Feauveau (CDF) 9/7-tap biorthogonal wavelet with irrational coefficients.

1. INTRODUCTION

It is well known that the discrete cosine transform (DCT), which is used in the JPEG image compression standard, suffers especially at low bit rates from blocking artifacts. In order to overcome this drawback, many discrete transforms with overlapping bases have been found. For example, wavelet transform with long overlapping bases and lapped transforms [1] have elegantly solved the blocking effects problems. However, from the computational complexity viewpoints, the implementation of wavelet transform is generally much more complex than that of the DCT. The lapped biorthogonal transform (LBT) can indeed completely eliminate annoying blocking effects [2], the computational complexity required by LBT is also less than that needed by the wavelet transform, and in some cases the LBT's coding performance even surpasses that of the CDF 9/7-tap biorthogonal wavelet transform [3]. Nevertheless, unlike the DCT and wavelet transform, lapped transforms have not yet been widely adopted. As Tran lately pointed out that "one reason is that the modest improvement in coding performance is not enough to justify the increase in computational complexity"[4]. In order to reduce the computational cost, Tran[4] suggested using lifting steps first introduced by Sweldens[5] for implementing LBT. However, the lapped transform introduced in [4] exists at least two drawbacks: (1)The DCT performed is still floating-point, so the floating-point multiplication is inevitable; (2)Since factor $\sqrt{2}$ scaling the first oddly symmetric DCT coefficient is approximated by $(25/16)$, its inverse is also approximated by $(16/25)$, so the lapped transform does not map integers to integers. In this paper, we consider a family of lapped biorthogonal transforms by rescaling the first evenly symmetrical DCT coefficient by a factor of $(1/\sqrt{2})$. The proposed transform called IntLBT is very high efficient because a series of integer lifting steps is all that is required and the main computational process is based on integer DCT(IntDCT). When the IntLBT is applied to image coding, the performance of IntLBT coder is compared with the results obtained for the popular CDF 9/7-tap wavelet. Furthermore, the blocking artifacts that the traditional DCT possesses have been avoided completely.

2. INTEGER LAPPED BIORTHOGONAL TRANSFORM

In order to describe IntLBT, we first restate the definition of lapped biorthogonal transform (LBT) introduced by Malvar [2]. For simplicity, we illustrate the definition of the LBT by the flowgraph shown in Figure 1. It is easy observed that N is the samples, to minimize the transform's complexity, the LBT bases have length $L = 2N$, and the first oddly symmetric DCT coefficient (i.e., the first AC coefficient) is multiplied by a factor of $\sqrt{2}$. To achieve IntLBT, in this paper we propose to use factor $(\sqrt{2}/2)$ rescaling the DC term of the intermediate DCT coefficient. Therefore, the proposed LBT can be

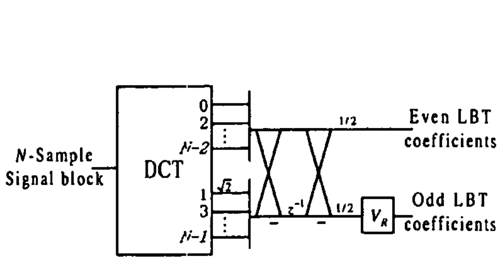


Fig.1 Flow chart of the LBT, with V_R defined in [1]

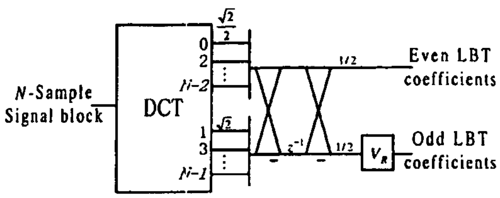


Fig.2 Flow chart of the new LBT

considered as a special case in [6] and the new developed LBT is illustrated as in Figure 2.

2.1. General IntLBT

Based on Figure 2, we now consider designing an efficient IntLBT of length-N.

Step 1: IntDCT

Consider the adjacent two block transforms, and let the inputs of length-N be X_1 and X_2, respectively. Compute the IntDCT-II [7, 8] of the sequences X_1 and X_2, and let the outputs be $Y_1 = (y_0^{(1)}, y_1^{(1)}, \cdots, y_{N-1}^{(1)})'$ and $Y_2 = (y_0^{(2)}, y_1^{(2)}, \cdots, y_{N-1}^{(2)})'$. The flow chart is expressed into

$$X_1 \Longrightarrow \boxed{\text{IntDCT-II}} \Longrightarrow Y_1$$

$$X_2 \Longrightarrow \boxed{\text{IntDCT-II}} \Longrightarrow Y_2$$

Step 2: Integer butterfly operations

From Figure 2 we see that the integer butterfly operations can be decomposed into following two stages.

Stage 1: Integer butterfly operations inside each block

Inside each block transform of Figure 2, after DCT is implemented, the following butterfly operations are expressed into:

$$\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} \frac{\sqrt{2}}{2} & 0 \\ 0 & \sqrt{2} \end{bmatrix} \begin{bmatrix} y_0^{(i)} \\ y_1^{(i)} \end{bmatrix} = R_{\frac{\pi}{4}} \begin{bmatrix} 2y_1^{(i)} \\ y_0^{(i)} \end{bmatrix}, \; i = 1,2, \quad (1)$$

and

$$\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} y_{2k}^{(i)} \\ y_{2k+1}^{(i)} \end{bmatrix}, \; i = 1,2; \; k = 1,2,\cdots,\frac{N}{2}-1. \quad (2)$$

Since $\begin{bmatrix} 1 & 1 \\ -1 & 1 \end{bmatrix}$ maps integers to integers, to achieve integer transform we use integer transform matrix $\overline{R}_{\frac{\pi}{4}}$ to replace $R_{\frac{\pi}{4}}$, in this case we define

$$\begin{bmatrix} \bar{z}_0^{(i)} \\ \bar{z}_1^{(i)} \end{bmatrix} = \overline{R}_{\frac{\pi}{4}} \begin{bmatrix} 2y_1^{(i)} \\ y_0^{(i)} \end{bmatrix}, \; i = 1,2, \quad (3)$$

and

$$\begin{bmatrix} \bar{z}_{2k}^{(i)} \\ \bar{z}_{2k+1}^{(i)} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} y_{2k}^{(i)} \\ y_{2k+1}^{(i)} \end{bmatrix} \quad (4)$$

where $i = 1,2$; $k = 1,2,\cdots,\frac{N}{2}-1$.

Stage 2: Integer butterfly operations between adjacent two block

From Figure 2 it is clear that after Stage 1 is completed, we need to implement butterfly operation between adjacent two transform blocks. This process itself maps integers to integers, and can be expressed as:

$$\begin{bmatrix} u_{2k} \\ u_{2k+1} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} \bar{z}_{2k+1}^{(1)} \\ \bar{z}_{2k}^{(2)} \end{bmatrix} \quad (5)$$

where $k = 0,1,\cdots,\frac{N}{2}-1$.

Step 3: Post integer rotations

Since V_R is a orthogonal transform matrix, it can be factorized into a number of plane rotations [4]. As in [4], we can use integer transform $\overline{V}_R$ to approximate V_R. When $\overline{V}_R$ is determined, post integer rotation is expressed by

$$[v_0, v_1, \cdots, v_{\frac{N}{2}-1}]' = \overline{V}_R [u_1, u_3, \cdots, u_{N-1}]'. \quad (6)$$

Therefore, $[u_0, u_2, \cdots, u_{N-2}, v_1, v_3, \cdots, v_{\frac{N}{2}-1}]'$ is the desired IntLBT output.

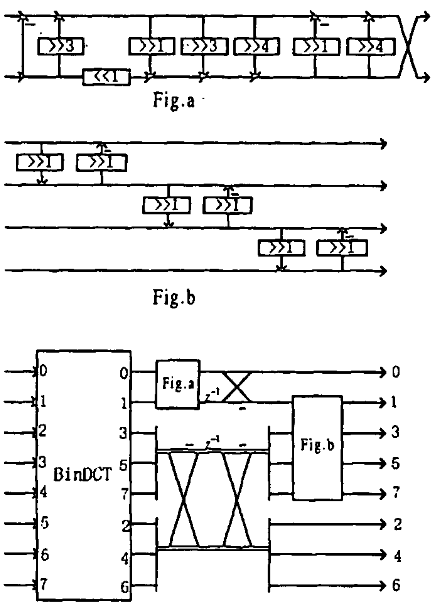


Fig.3 Flow chart of 8×16 IntLBT, with BinDCT defined in [8] as BinDCT-B, where "<<" denotes left shifts, ">>" denotes right shifts

2.2. *N*=8 IntLBT

In practice, to reduce complexity, the length N is not too big. We consider N=8. Let

$$\bar{R}_{\frac{\pi}{4}} = \begin{bmatrix}1 & -\frac{7}{16}\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ \frac{13}{16} & 1\end{bmatrix}\begin{bmatrix}1 & -\frac{7}{16}\\ 0 & 1\end{bmatrix}, \qquad (7)$$

and

$$\bar{R}_{0.13\pi} = \bar{R}_{0.16\pi} = \begin{bmatrix}1 & 0\\ \frac{1}{2} & 1\end{bmatrix}\begin{bmatrix}1 & -\frac{1}{2}\\ 0 & 1\end{bmatrix}, \qquad (8)$$

the detailed flow chart of 8×16 IntLBT is illustrated as Figure 3.

3. APPLICATION IN IMAGE CODING

In this section we show the experimental results, analyze and compare the performance of this IntLBT algorithm and other classical discrete transforms in image coding. To be fair, the same SPIHT's quantizer and entropy coder [9] are exploited to encode the coefficients of every transform. The transforms in comparison are 8×8 DCT, 8×8 binDCT [8], the new 8×16 IntLBT, and the popular CDF 9/7-tap wavelet with a six-level decomposition.

bpp	DCT	binDCT	CDF 9/7 wavelet	IntLBT
1	39.52	39.08	40.06	39.54
0.5	36.04	35.80	36.94	36.34
0.25	32.54	32.36	33.82	33.27
0.125	29.17	29.01	30.60	30.14
0.0625	26.28	26.25	27.65	27.13

Table 1: PSNR evaluation for Lena, in dB

bpp	DCT	binDCT	CDF 9/7 wavelet	IntLBT
1	35.86	35.52	36.24	35.90
0.5	32.39	32.21	32.79	32.59
0.25	29.59	29.63	30.34	29.94
0.125	27.65	27.45	28.22	28.00
0.0625	25.66	25.58	26.16	25.99

Table 2: PSNR evaluation for Goldhill, in dB

Bpp	DCT	binDCT	CDF 9/7 wavelet	IntLBT
1	35.96	35.42	36.29	36.97
0.5	30.90	30.57	31.24	31.94
0.25	27.03	26.79	27.43	28.18
0.125	24.27	24.05	24.44	25.27
0.0625	22.00	22.32	22.99	22.75

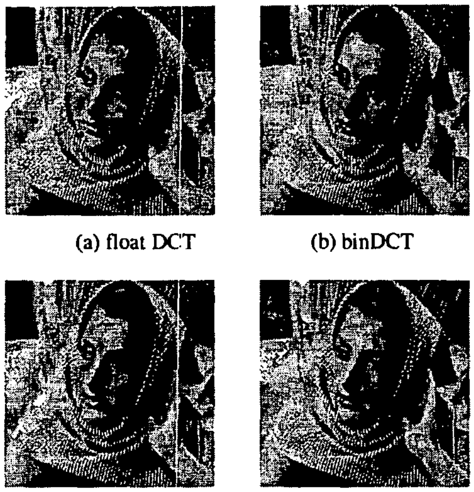
Table 3: PSNR evaluation for Barbara, in dB

Table 4: Comparison of transform Complexity (operations needed per transform coefficients)

	DCT	binDCT	CDF 9/7 wavelet	IntLBT
No. of integer additions.	0	7.75	0	15
No. of integer shifts	0	3.5	0	6.75
No. of float additions	7.25	0	10.5	0
No. of float multiplications	3.25	0	7.875	0

In the three block transform cases, we use the modified zerotree structure in [10], where each block of transform coefficients are treated analogously to a full wavelet tree, and three more levels of integer 5/3 wavelet decomposition are employed to decorrelate the DC subband further. The objective coding results (PSNR in dB) for standard 512×512 Lena, Goldhill and Barbara test images are tabulated in Table 1~3.

It can be observed that the IntLBT outperforms DCT and binDCT, on three test images at all bit rates. Compared to CDF 9/7-tap wavelet transform, the IntLBT is also quite competitive. For example, for a smooth image such as Lena, the PSNR is about 0.5dB below.



(a) float DCT (b) binDCT

(c) CDF 9/7 wavelet (d) IntLBT

Fig. 4 Quarter portions of reconstructed Barbara images at bpp=0.25

However, for more complex image in the most case the IntLBT even surpasses the CDF 9/7-tap wavelet. The PSNR improvement can reach as high as 0.83dB. Besides, the visual quality of its reconstructed images is also superior, as demonstrated in Figure 4, blocking effects is completely eliminated.

Another key advantage over CDF 9/7-tap wavelet transform is the low computational complexity of the IntLBT, the comparison of complexity between the IntLBT and other popular transforms is tabulated in Table 4. From the Table 4 we know that the computational complexity that needed by the proposed IntLBT is even less than that required by 8×8 DCT because the floating-point multiplication and addition in the IntLBT is avoided completely.

4. CONCLUSION

In this paper, we have presented a lapped biorthogonal transform that can map integer to integers. Using this lapped transform, a new family of integer lapped biorthogonal transform called IntLBT for image coding applications is also achieved. The IntLBT is found to have competitive performance compared to the much more complex CDF 9/7-tap wavelet transform. Simulation results also demonstrated that the IntLBT has significantly less blocking artifacts, higher peak signal to noise ration, and better visual quality than the floating-point DCT. By using integer arithmetic operations, the implementation complexity of IntLBT is reduced considerably compared to the implementation of floating-point lapped biorthogonal transform.

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